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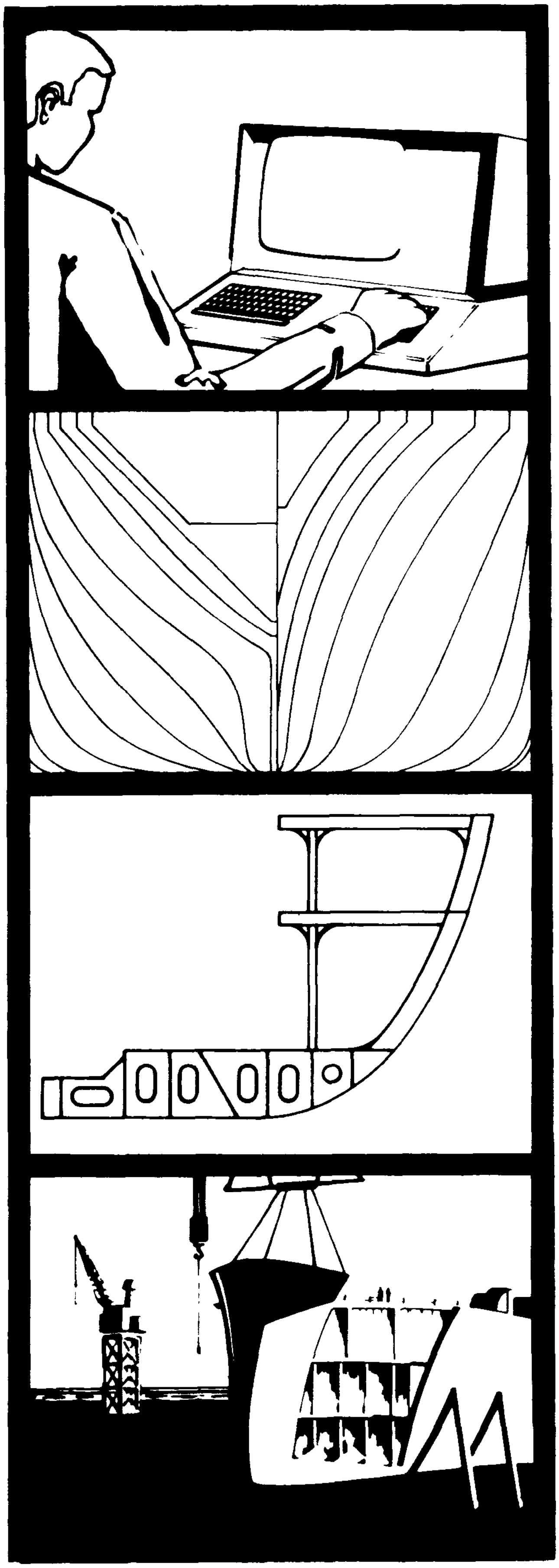

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ECONOMICS OF COMPUTERS IN SHIPYARD PRODUCTION CONTROL

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ABSTRACT

Private shipyards are under heavy pressure to improve productivity. So are the naval shipyards. Like the private shipyards, naval shipyards are focusing on improved production planning, scheduling, labor/progress data collection, and industrial engineering as the main thrust of their productivity improvement programs. Unlike the private shipyards, however, the naval shipyards are drawing heavily on the use of computers to support these functions. One project, the subject of this paper, is of particular interest since a computer is used to integrate planning, scheduling, work-in-process tracking and labor collection functions with engineered labor standards to provide a closed-loop production control system for a key production shop at the Portsmouth Naval Shipyard. This system achieved operational status during the spring of 1980. A complete economic history of its initial economic justification, development and operating costs and preliminary indications of payback are now available. Since the design of this system makes it quite appropriate for private shipyard use, the data included within this paper should be of interest to those concerned with the economics of computers in private shipyard production control functions. Results of this project are correlated with the objectives and results of the National Shipbuilding Research Program, as appropriate.

INTRODUCTION

The joint Maritime Administration/Industry National Shipbuilding Research Program has concluded that major improvements in shipyard productivity can be achieved by better planning and scheduling, by more accurate and reliable performance measurement, and by more effective use of industrial engineering techniques - particularly engineered methods and labor standards. However, improvements in these four areas by themselves will contribute little to improving productivity. They must be cemented together in a closed-loop control system, with all its elements in balance and in tune with the production environment in which they must function. Failure to recognize and apply these basic principles will result in the expenditure of lots of money with little improvement to show for the investment.

The subject of this paper is the development of a closed-loop system (Figure 1) for controlling operations of the Inside Machine Shop at the Portsmouth Naval Shipyard. Devel'opment of this system was justified on economic grounds. Initial results from six months of operational experience clearly substantiate the wisdom of the Portsmouth decision to proceed with the implementation of this system. Although the Navy has not been an active participant in the National Shipbuilding Research Program, findings of the experiment in the use of labor standards and closed-loop control at the Hardings steel fabrication plant of BIW[1] provided the basic economic justification for the Portsmouth venture.

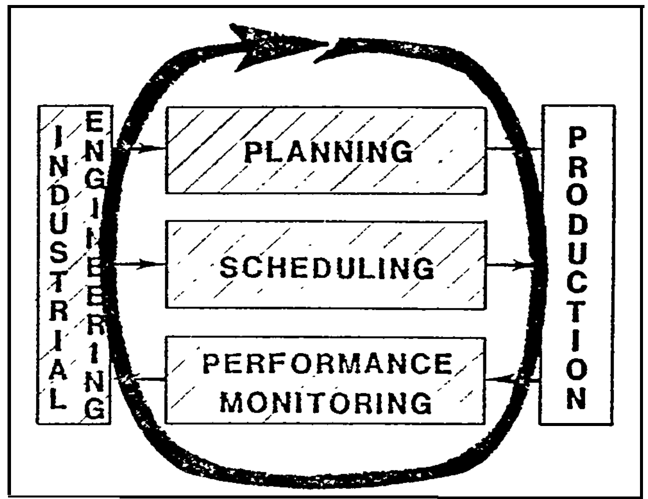

Figure 1. The Closed-Loop Production Control System

THE BIW HARDINGS EXPERIMENT

The Bath Iron Works Corporation (BIW) postulated that one

[1] References listed at the end of the paper.

of the prime contributing factors to the high cost of constructing ships in U.S. shipyards was too much slack in construction schedules; furthermore, that this slack could be removed by the use of engineered labor standards. BIW also had the foresight to recognize that the imposition of labor standards would be pointless unless these were imbedded in a closed-loop system that would measure actual performance against standards in order that proper and effective action could be taken when necessary.

The Maritime Administration and the Ship Production Committee of SNAME endorsed testing of engineered standards and closed-loop control in a live production setting. BIW then included in its Ship Producibility Research Program a research task (Task O-2) to investigate the application of engineered standards and closed-loop control toward reduction of fabrication costs in the Hardings Plant. The results[1] from this limited experiment were dramatic. Adherence to schedule was improved (Figure 2) from an average of 3.2 weeks late to zero weeks late. Steel fabrication costs (Figure 3) were reduced by twenty percent.

Claims to improvements of this magnitude are naturally suspect and usually require confirmation before anybody takes them seriously. A moments reflection on this experience, though, suggests that the results of the Hardings experiment are not unreasonable at all, but rather what we should have expected.

There is, in fact, a lot of slack in ship construction/overhaul schedules which we must learn to eliminate. As Lou Chirillo has pointed out[2], each day squeezed out of a construction schedule is equivalent to saving $20,000 in interest on the money to finance work-in-process. Although the naval shipyards are not confronted with construction financing costs, they do recognize the fact that shortening the length of an overhaul saves money. In the case of submarines, each day pared off an overhaul saves between

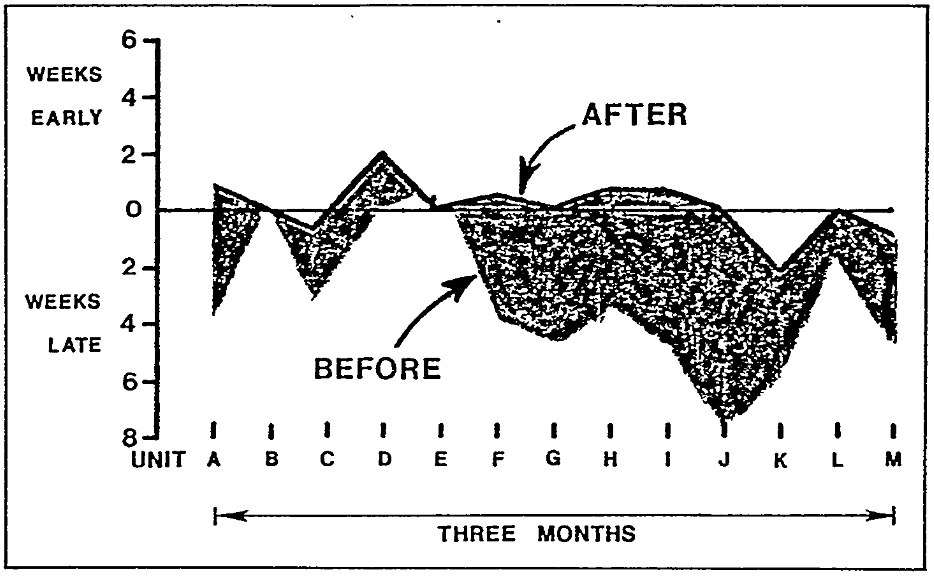

Figure 2. Improvement in Adherence to Schedule[1]

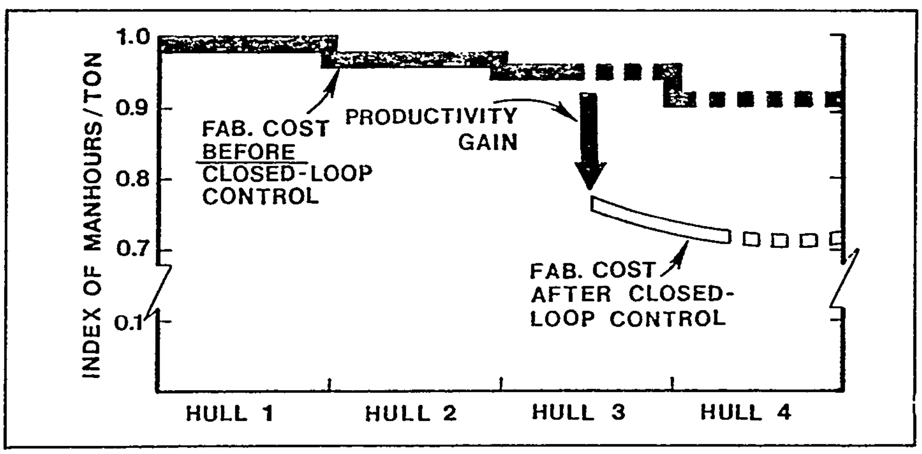

Figure 3. Reduction in Fabrication Costs[1]

$50,000 and $100,00. So reducing the duration of a construction or overhaul project by only a few days can still save a lot of money.

These two data points strongly suggest that one important way of reducing construction/overhaul costs is to compress construction/overhaul times[3] We all know, however, that if schedules are compressed too far, then costs tend to grow because of overtime, re-work, interference, delay and disruption from late material and late drawings, etc.

Cost of construction or overhaul as a function of time, therefore, forms a cup-shaped curve, (Figure 4A), where both expediting costs for excessively short schedules and investment costs for excessively long schedules tend to drive costs above some minimum.

Results of several projects within the National Shipbuilding Research Program[4] support the hypothesis that the U.S. shipbuilding industry tends to operate in the region of excessively long construction periods (Figure 4B). cost profiles for naval ship overhauls tend to be like that shown in Figure 4C. Early phases of an overhaul tend to drag; later phases entail high expediting costs in order to finish on schedule. In both cases there are significant opportunities for reducing costs (Figure 4D). How are these opportunities to be exploited? By getting both slack and congestion out of the flow of work. How can this be done? By controlling work at the right level of detail.

FINDING THE RIGHT LEVEL OF DETAIL FOR CONTROL OF WORK

What is the right level of detail? It is the level that minimizes congestion and eliminates unnecessaly slack which, in turn, depends on the nature of the work and the working environment.

The subject of this paper is a system now operating in the Inside Machine Shop of the Portsmouth Naval Shipyard.

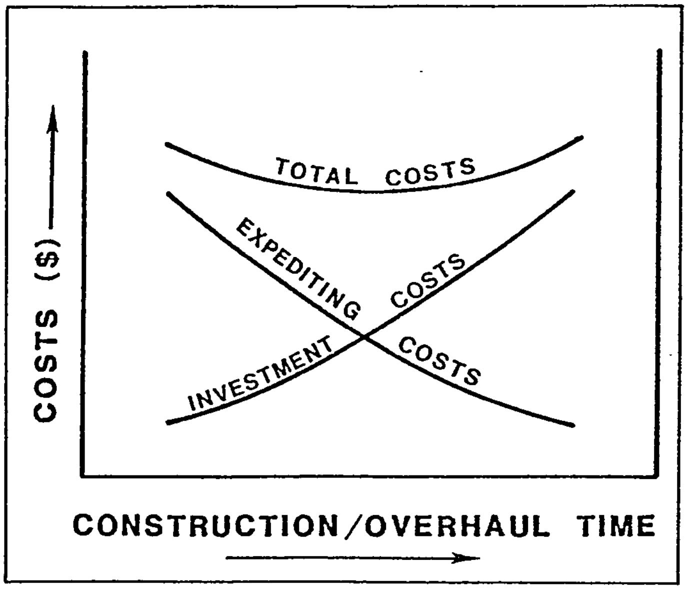

Figure 4A. Construction/Overhaul Cost/Time Relationship

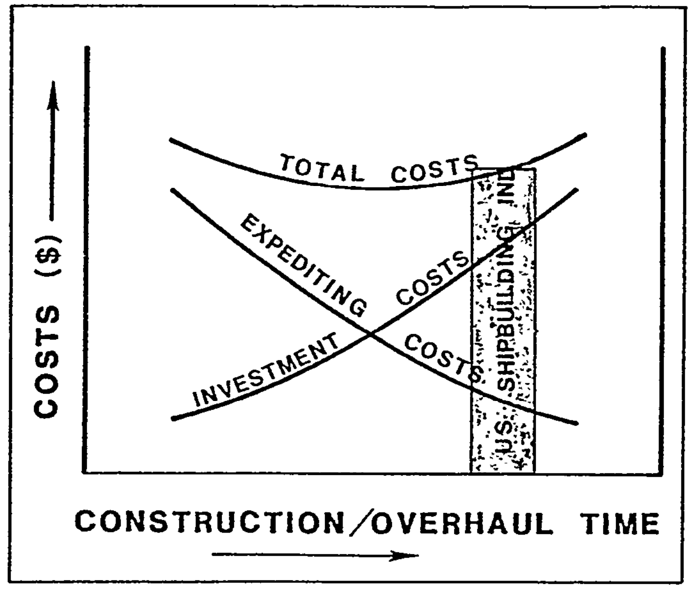

Figure 4B. Cost/Time Posture of U.S. Shipbuilding Industry

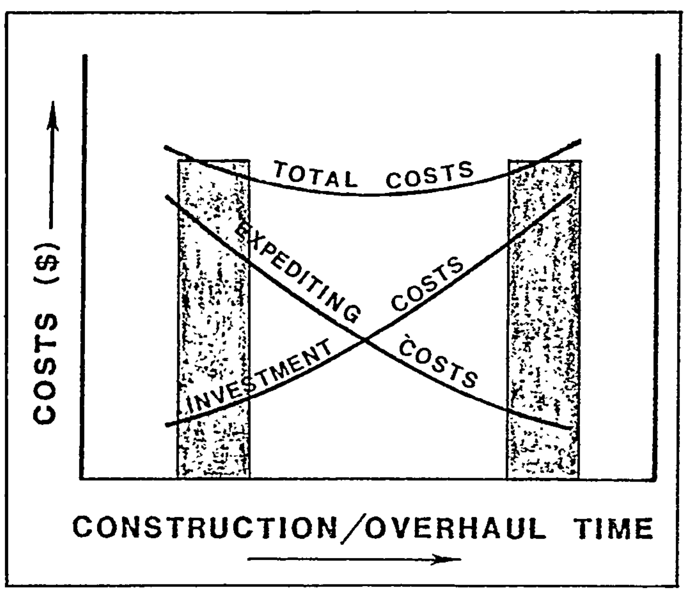

Figure 4C. Cost/Time Posture of Overhaul Work

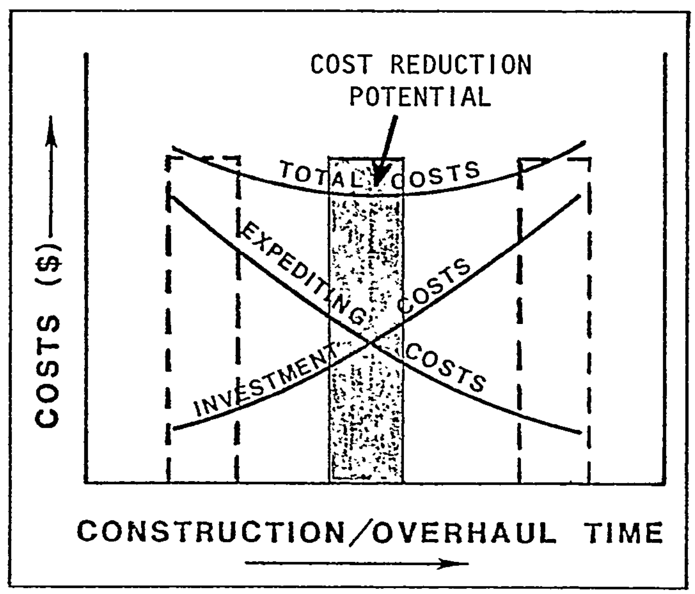

Figure 4D. Cost Reduction Potential Through Management of "Time"

Virtually all of the work in this shop involves the refurbishment and repair of components, like valves, actuators, pumps, shafts and bearings, used in submarines. To understand the structure of the work within this shop and its production control problems, we should know a little bit about what is involved in overhauling submarines.

A typical overhaul (Figure 5) costs between $50 and $100 million, depending upon type and class, and consumes between 1.5 and 2.5 million man hours. Eighteen months is the target overhaul time period, but most take somewhat longer - some as long as two years. As a point of reference, a new RO/RO will cost about $75 million and a new 35,009 DWT tanker about $50 million. In terms of the size and cost of the work package, overhauling a submarine is roughly equivalent to constructing a commercial ship.

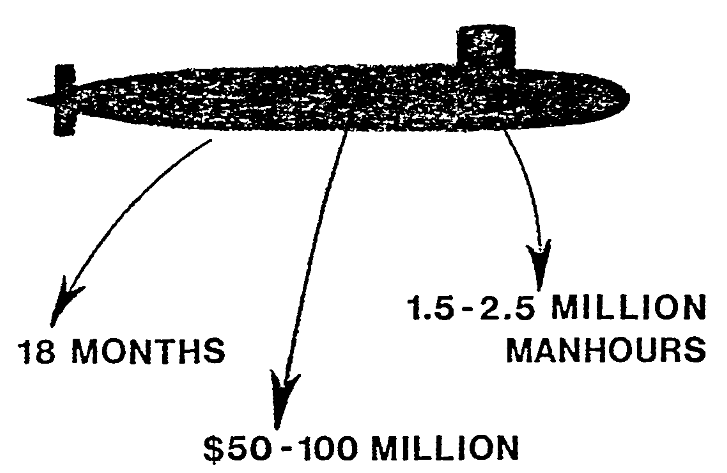

Figure 5. Submarine Overhauls

There are about 50 to 60 productive cost centers (that is, shops, departments, etc.) within the shipyard that provide direct support to submarine overhauls. Distribution of work between these various work centers for an overhaul is shown in Figure 6. The pipe, outside machine and inside machine shops have been separately identified in this figure because these three shops really control the overhaul duration and cost, although they contribute collectively only 20% of total direct labor.

Pipe and outside machine shop work is conducted largely aboard the submarine, whereas the inside machine shop treats

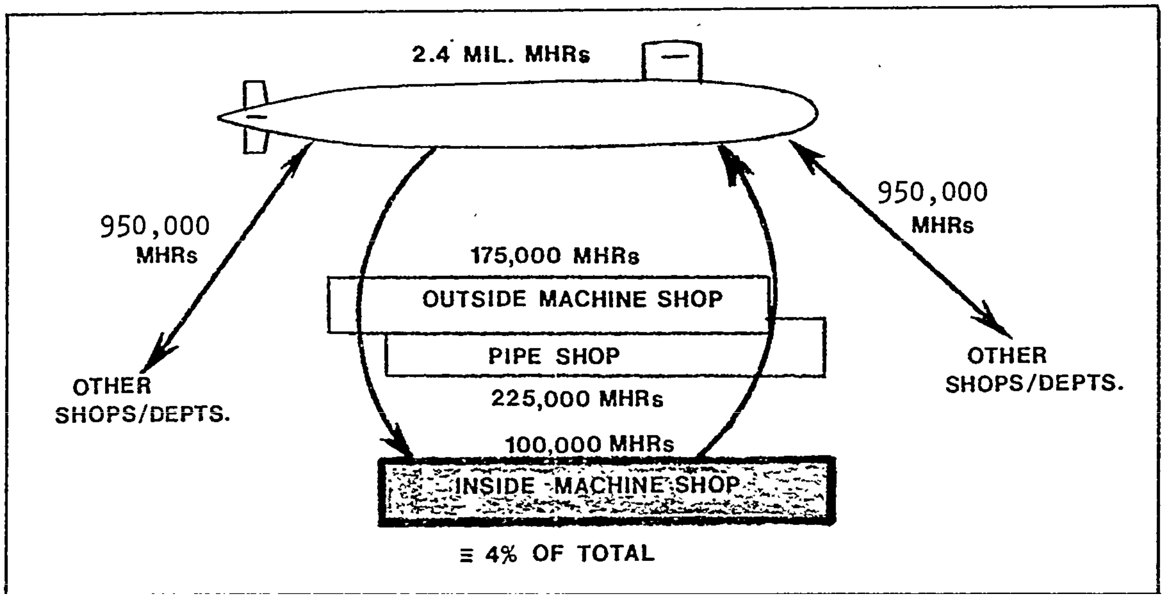

Figure 6. Distribution of Labor for Submarine Overhauls

components removed from the submarine by the other two shops. The flow of overhaul work, therefore, begins with removal of components from the submarine by the outside shops. Components are shipped to the inside shops where they are repaired and refurbished. The components are then shipped back to the outside shops for reinstallation and test.

The test phase of an overhaul is complex and takes many months. Components are tested individually; then in combination; then as sub-systems; and finally as entire systems under various anticipated operating conditions.

Shipyard performance during the reinstallation and test phases of an overhaul (which actually comprise over 50% of the overhaul duration) are critically dependent on Shop 31 (the inside machine shop) meeting component delivery schedules. Shop 31's schedule adherence problem is complicated by the fact that the last components removed from a submarine are usually the first to be reinstalled to avoid interference problems. These components appear on the Shop 31 receiving dock when the shop is already fully loaded. Unless they are given special scheduling treatment, they will invariably be completed late.

Shop 31 performance has, therefore, a direct impact on the cost and duration of a submarine overhaul -- even though it contributes only 4% (Figure 6) of the labor total.

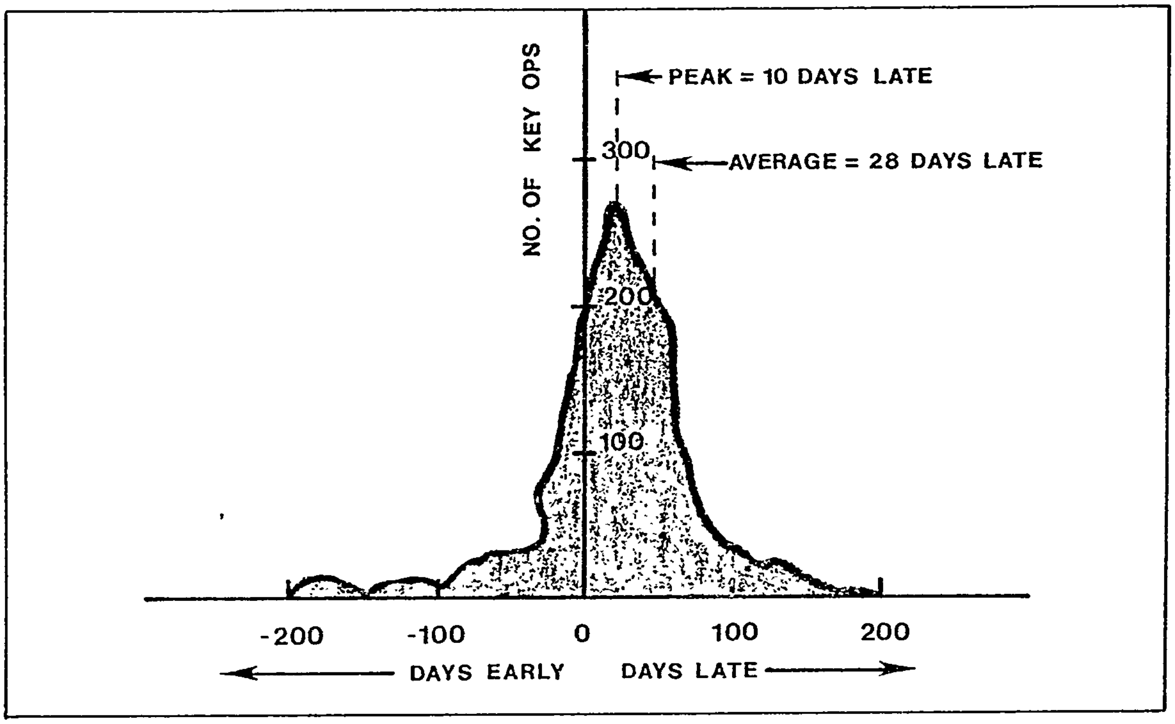

Figure 7. 1976 Performance-To-Schedule Profile of Shop 31

What has Shop 31's performance to schedule been? Not exemplary as can be seen from Figure 7. This distribution represents a sample of about 1300 jobs worked by the shop during 1976. For reasons stated in the BIW Manual on Production Oriented Planning[3], the spread of this distribution is really of greater concern than the average lateness of twenty-eight days, because the spread indicates that the "production control system" is not really exerting much control.

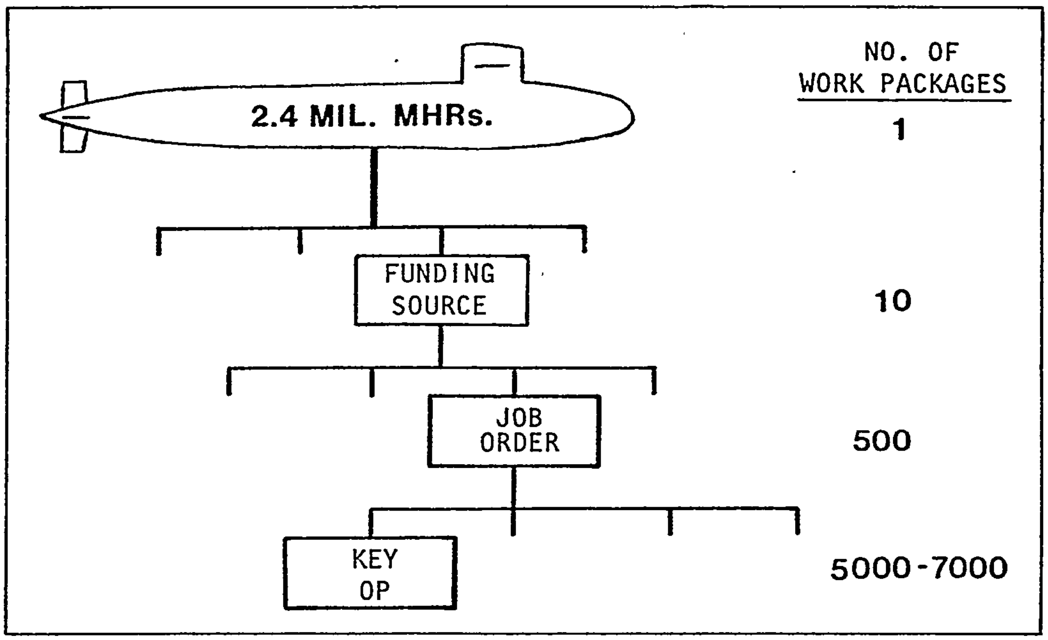

Figure 8. Work Breakdown Structure for Submarine Overhauls

The naval shipyards, since the early 1970's, have used a centralized, batch ADP system-to assist the central planning, production, supply and financial functions. To facilitate control of overhaul work and the collection of material and labor expenditure data, these shipyards have adopted the standard work breakdown structure shown in Figure 8. The Key OP, or more properly Key Operation, is the work package that is issued to the shops. It both specifies the work to be accomplished and authorizes its accomplishment. Key Op records within the central ADP system are used to collect material and labor expenditures, and to track progress against scheduled completion dates. In size, Key Ops average 300 to 400 man-hours. The Key Op, then, is the basic vehicle for planning and scheduling work and for monitoring shop performance.

Work is issued to Shop 31 from central planning in the form of Key Ops. A single Key Op will cover, on the average, repair of about 3 components, but may cover as many as 100 or as few as one (Figure 9). Within Shop 31, repair of each

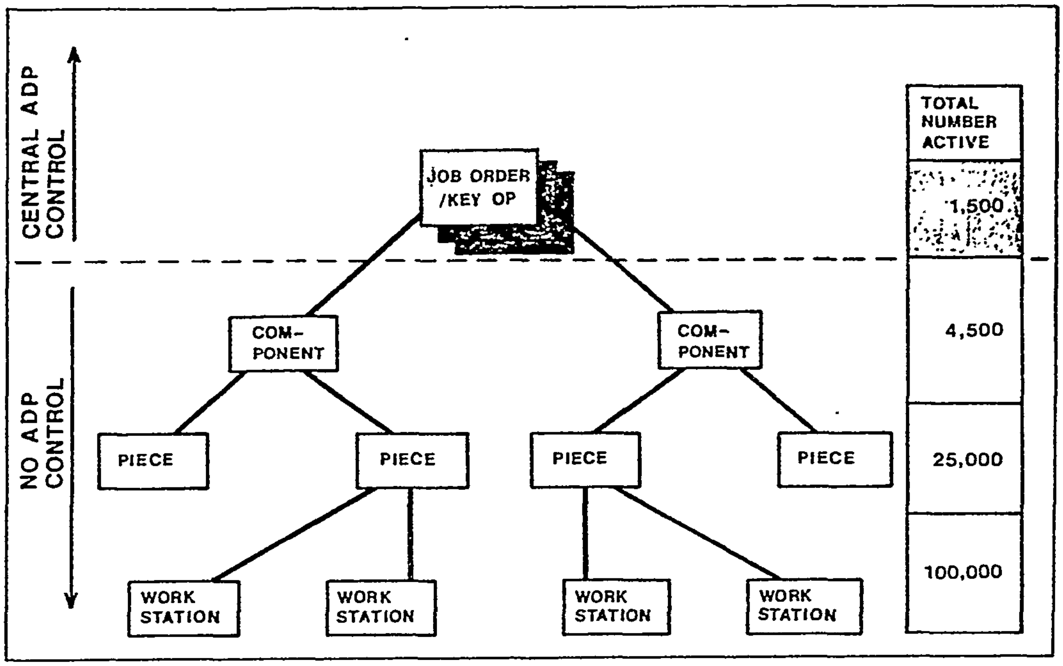

Figure 9. Work Breakdown Within Shop 31

component must be treated separately since each **item** removed from the ship must be reinstalled (or a replacement installed), and the reinstallation must be documented and certified. In point of fact, within the pipe, inside machine, and outside machine shops, work is focused on the handling of single components and their constituent parts -- not on the parent Key Op. But as shown in Figure 9, controlling work at the component level involves tracking the status of literally tens-of-thousands of items. This is a prodigious task.

The schedule performance of Shop 31 (Figure 7) can be traced directly to the fact that the shop was never allowed the where-with-all to control operations at the level required -- namely, at the component level. Historically the shop has been overwhelmed by the shear numbers of items and activities it had to track; it had neither the facilities nor the people to keep matters under control. Virtually the entire shop office staff was involved in planning and issuing jobs; people were not available to close the control loop (Figure 10).

On the basis of these facts, it was concluded that shop performance could be improved only if control was extended to the component level. Even so, there was still a legitimate and important management question whether control should actually be established at this level. To answer this question in a reasonable way an analysis of the economic factors involved was required.

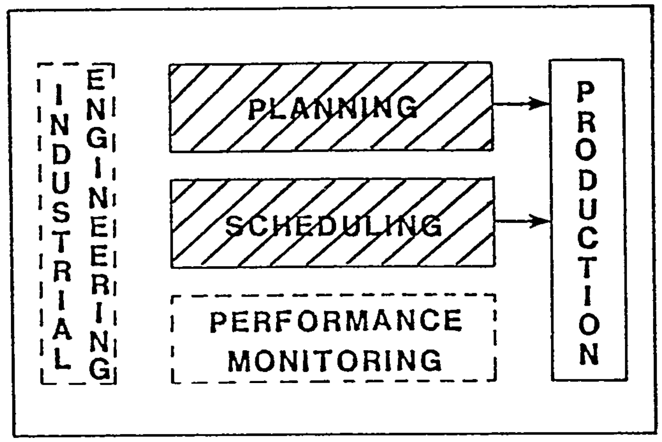

Figure 10. The Shop Control System in 1976

General speaking, breaking down the work into smaller and smaller work packages permits tighter control. Tighter control permits more precise scheduling which, in turn, reduces congestion and eliminates slack. Elimination of slack permits compression of the overall schedule which saves money -- as we noted earlier.

Increasing control can reduce cost as shown in Figure 11A. However, there comes a point in work package division where all of the savings have been captured. Further subdivision of the work beyond that point does not contribute any further savings, so the curve flattens out.

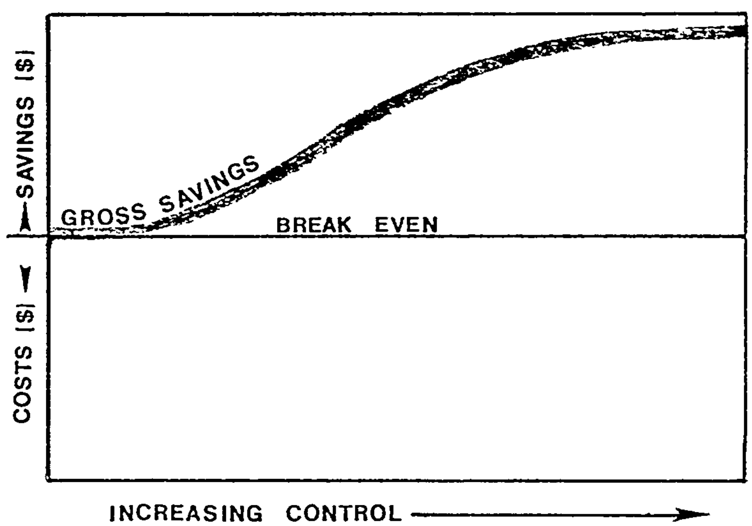

Figure 11A. Savings From Increased Control

In this world, we never get something for nothing; we have to pay for increased control (Figure 11B) -- for people, for paper, for equipment, for telephones and desks for the people, etc. The slope of the curve increases with more detailed control because the number of work packages usually increases exponentially with the number of levels in the work breakdown structure (Figure 8). To find out whether increasing the level of control is sensible requires subtracting the expected costs from the expected savings (as we have done in Figure 11C) to find out whether increasing the level of control costs more than it saves. As long as the level of control lies to the left of the shaded bar, every dollar spent in increasing control is more than recovered in the returned savings. When the level of control is to the right of the shaded bar, every additional dollar spent in increasing control yields less than a dollar in return. The right level of detail

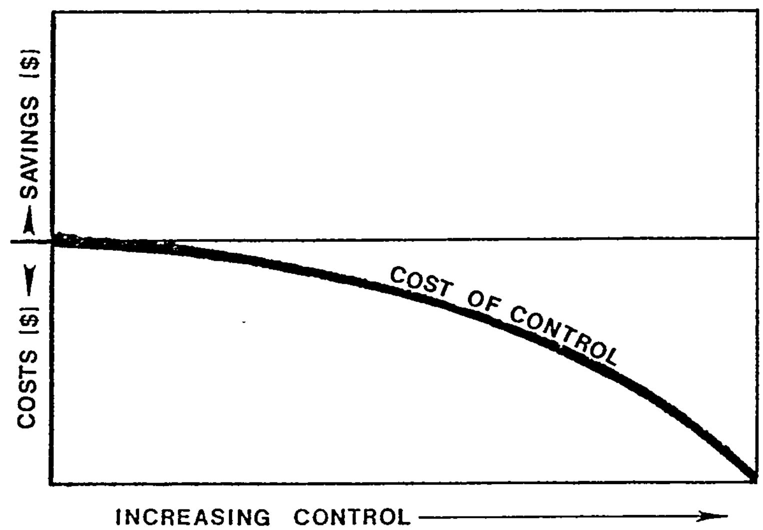

Figure 11B. Cost of Increasing Control

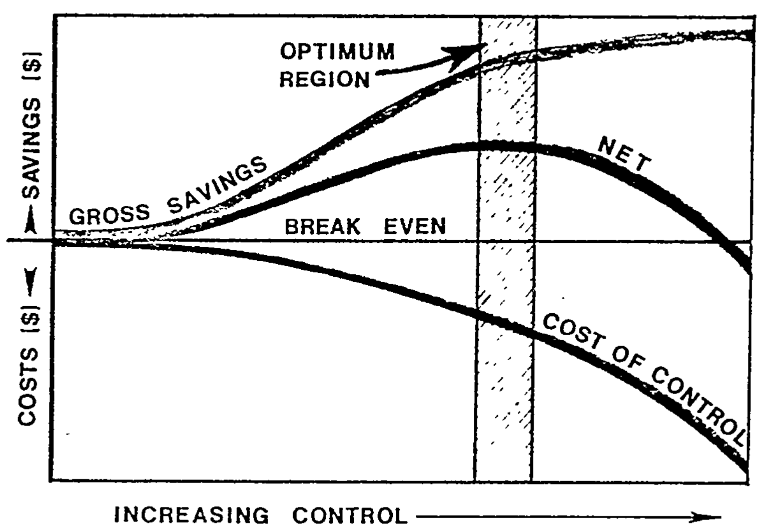

Figure 11C. Cost/Payback From Increasing Control for control is, then, that level which yields the greatest net savings, namely where the shaded area intercepts the horizontal axis.

ECONOMIC ANALYSIS OF THE INSIDE MACHINE SHOP CONTROL SYSTEM

Returning to the Shop 31 control system problem, deciding whether to increase control to the component level meant determining whether the expected savings from increased control would more than cover the associated costs.

To estimate potential savings, operational audits of work flow in the three shops (inside machine, outside machine and pipe) were conducted. Results of these audits are summarized in Table 1. (The audit team actually found expected savings to be much higher, but to be on the conservative side they scaled their findings down by a factor of two.)

FUNCTION	SAVINGS
MACHINE SHOP INCREASED PERF.	$120
COST REDUCTION CUSTOMER SHOPS	$200
TOTAL ANNUAL SAVINGS	$320

Table 1. Expected Annual Savings from Increased Control ($ in Thousands)

To estimate costs, the study **team** configured two systems to implement controls at the component level within the shop: a completely manual system and a system employing a minicomputer. Functional scope of these two systems was the same. It covered:

- Producing shop work instructions
- Tracking work-in-process
- Collecting labor and material expenditures
- Work station load projection
- Scheduling jobs for level loading work stations.

Control over jobs was, therefore, extended (Figure 12) to cover the complete routing of each job at the work station or machine level.

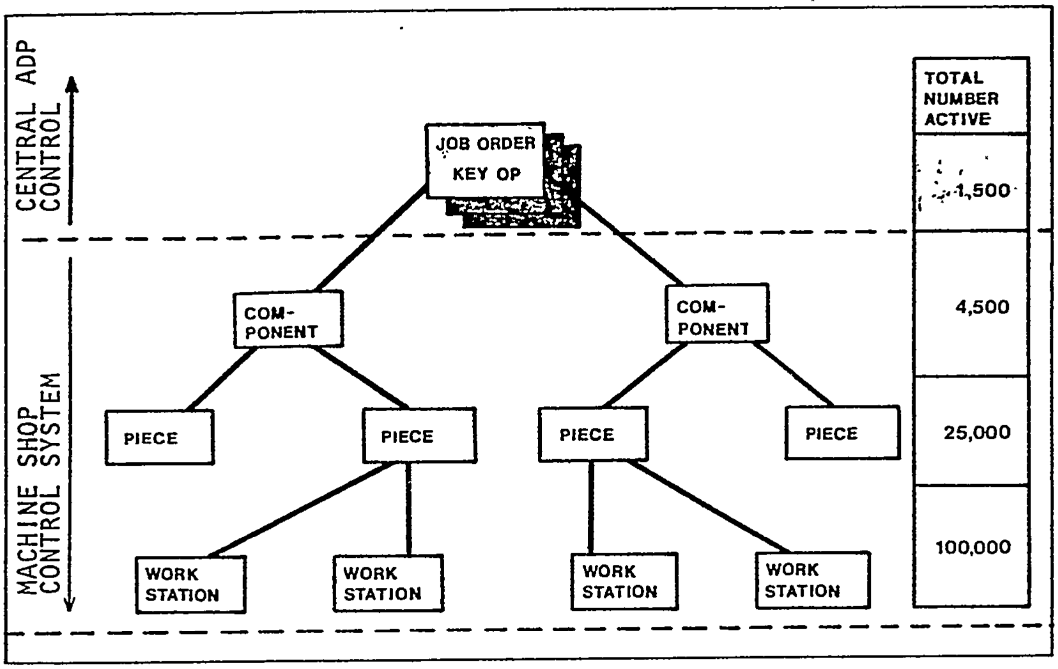

Figure 12. Level of Control for the Inside Machine Shop Control System

The manual system required adding 20 people to the shop planning staff -- each of whom would be responsible for tracking about 200 active jobs. Estimated annual costs of this implementation option are summarized in Table 2.

With annual costs of about $500 thousand and savings of only $320 thousand, the manual system would lose around $180 thousand per year -- clearly not a desirable situation. If the manual method were the only method available, it would not pay to carry production control to the component level within Shop 31. Shipyard management would have to live with Shop 31 performance analogous to that shown in Figure 7.

20 ADDITIONAL PLANNERS	
200 JOBS EACH	
HOURLY WAGES =	$9.00
FRINGE =	33%
COST/MHR =	812.00
COST/MYR =	$24,900
TOTAL ANNUAL COST =	$500,000

Table 2. Cost of the Manual System

FUNCTION	SAVINGS
C.lerical and Expediting	$140
Inside Machine Shop Performance Improvement	120
Pipe/Outside Machine Shop Performance Improvement	200
TOTAL ANNUAL SAVINGS	$460

Table 3. Annual Savings From Minicomputer Option ($ in Thousands)

Investigating the minicomputer implementation option revealed that many routine clerical operations within the shop office could be automated with attendant savings in personnel. Shop planners were spending about 35% of their time physically chasing jobs on the shop floor and searching status records. Thus, in addition to savings from improved inside and outside shop performance, the minicomputer option also captures savings that were not possible with the manual option (Table 3). Estimating the cost of the minicomputer system required the following actions:

- Design of the system
- Preparation of a development plan
- Estimating development costs
- Estimating hardware costs
- Estimating recurring O&M costs

The system was designed to perform the same functions that the manual system did, namely:

(1) Printing shop work instructions

(2) Tracking work-in-process

(3) Collecting labor and material expenditures

(4) Maintaining a library of standardized work instructions

(5) Loading work centers and scheduling jobs

The development schedule covered a period of three years and was divided into three phases. Phase I was to implement items (1), (2) and (3) above; Phase II item (4); and Phase III item (5). The expected costs of system development are shown in Table 4.

		1979	1980	1981
PHASE I	PROGRAMMING	$ 70	$ 20	
	HARDWARE & O & M	80	20	
PHASE II	PROGRAMMING		40	
	HARDWARE		20	
PHASE III	PROGRAMMING			$ 60
	HARDWARE			20
	TOTAL	$ 150	$ 100	$ 80

Table 4. Development Cost of the Minicomputer System

Since the implementation of this system was to take place over a period of three years, the savings estimates had to be factored so that they were properly synchronized with the ex- capabilities of the system, as shown in Table 5.

	PHASE I	PHASE II	PHASE III
CLERICAL & EXPEDITING	$ 90	$140	$140
INSIDE MACHINE SHOP PERFORMANCE IMPROVEMENT	--	*	120
PIPE/OUTSIDE MACHINE PERFORMANCE IMPROVEMENT	200	200	200
TOTAL	$290	$340	$460

*DOES NOT INCLUDE SUBSTANTIAL SAVINGS FROM ENGINEERED LABOR STANDARDS

Table 5. Gross Annual Savings From Shop Control System ($ in Thousands)

The hardware configuration specified for Phase I is shown in Figure 13. There were to be initially six shop floor terminals for the collection of job status, job movement, and labor expenditure data. Four CRT terminals were to be used

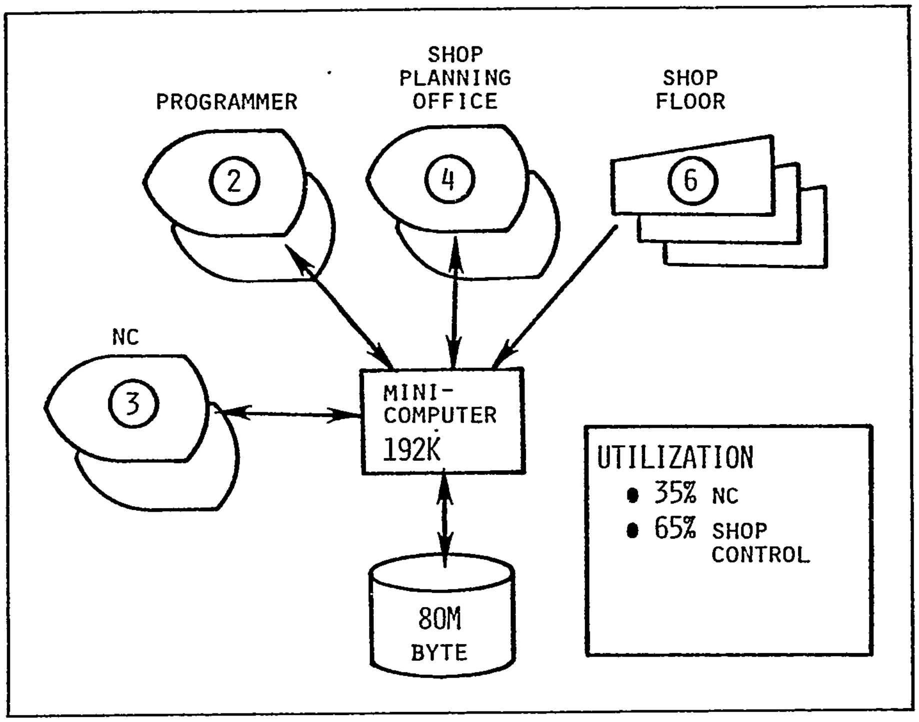

Figure 13. Minicomputer Hardware Configuration

in the shop office for entry of shop work instructions and for on-line inquiry into job status. The other five terminals were to serve NC and programming functions.

It was planned that hardware capacity grow to match phased growth in system capabilities. Additional equipment needs included expanding the memory, adding more disk storage and increasing the number of terminals on the shop floor.

The projection of costs and savings made in 1977 for the minicomputer system is shown in Figure 14. As can be seen in this figure, projected savings far outweigh development and operating costs; development costs would be fully recovered by the end of three years, and thereafter yield a payback of over $300 thousand a year. The negative slope of the cost curve after completion of system development reflects the fact that the equipment was to be acquired on a lease/purchase arrangement rather than by direct purchase.

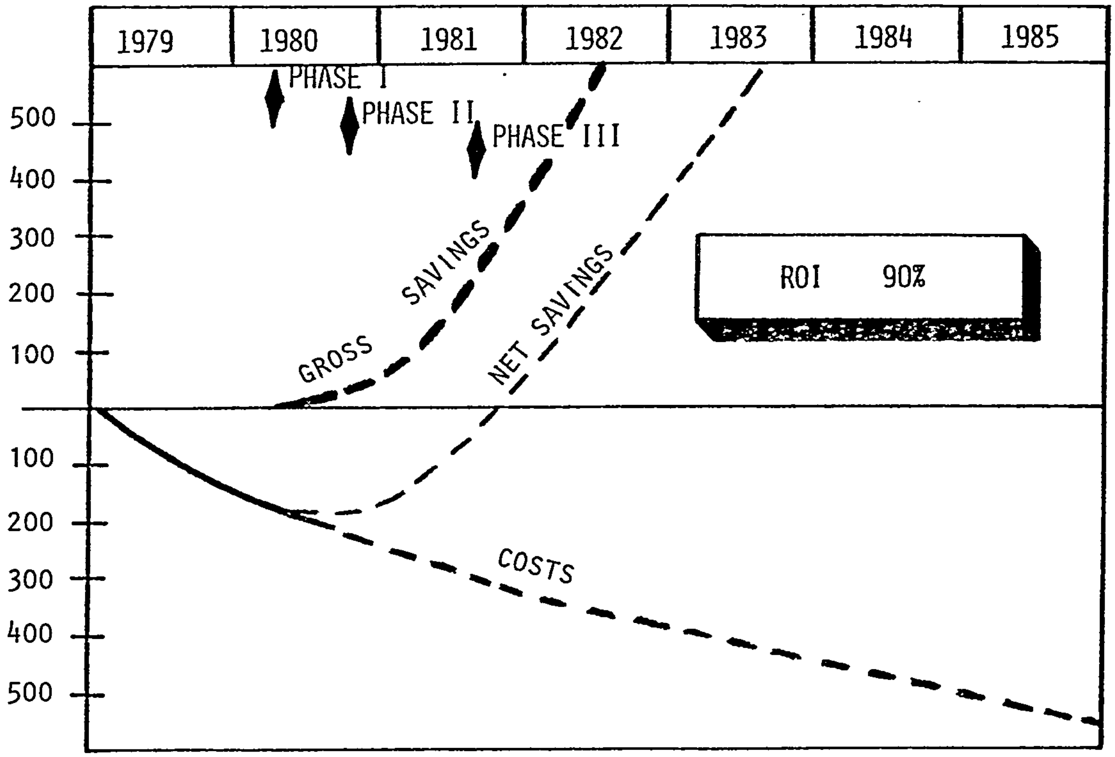

Figure 14. Cost/Payback Curves for Minicomputer System

Return-on-investment for this alternative over the **seven** year period shown was calculated (on the basis of the cost/savings estimates) to be a healthy 90%.

This analysis pretty much demonstrated that control of Shop 31 production operations at the component level was not only economically feasible but promised substantial dollar savings, if it were implemented using minicomputer support. The acquisition of the hardware was therefore approved, and system development actually began in January of **1979.**

EARLY RESULTS

Phase I of the system, which includes issuing shop work instructions and collection of labor expenditure and job status information, was brought on-line in January of 1980. Over the course of the summer all jobs in Shop 31 were brought on the system, so that it now provides **100%** coverage of all shop work. Manual expediting has virtually ceased; savings projected in **1977** in this area are being realized today. Development costs and the implementation schedule adhered to original plans quite well. In fact, the Phase I programming effort took only one-and-a-half person years.

There are two reasons for this track record. First, there was a dedicated effort to keep the system simple and focused on the fundamental shop problems. Second, and probably more important, development of the, system was accomplished within the shop itself so there was continual interplay between production and data processing people. Each learned to appreciate the other's problems.

Not enough operational data has been collected as yet to measure performance improvements in the outside shops with any degree of confidence. However, the pipe and outside machine shops are even now being given far better component delivery information for scheduling reinstallation and test activities than before. Major improvement should become apparent as soon as procedures are worked out for integrating the component repair and reinstallation schedules of all three shops.

Phase II will be brought on-line this fall and Phase III in about a year. Phase II should see additional improvement in the shop planning area through a reduction in the clerical burden involved in preparing shop work instructions. Incidentally, a combined word processing/data processing system that has been operational in the shipyard central planning office has already demonstrated a 30% reduction in planning costs per overhaul through elmination of many routine clerical functions.

CONCLUSIONS

What do we conclude from this experience?

First, whether it makes sense to use computers in shipyard production control is simply a question of economics, namely, whether the savings from increased control more than cover the cost of the system and provide a reasonable rate of return. Generally speaking, for small shops with fewer than 100-200 active jobs at any given time, a well-thought-out manual system is probably the most cost-effective (Figure 15). Beyond this point automated systems become economically attractive. When the number of jobs exceeds 300 to 400, ADP becomes almost mandatory to exercise close control over productive work and to reap the benefits therefrom.

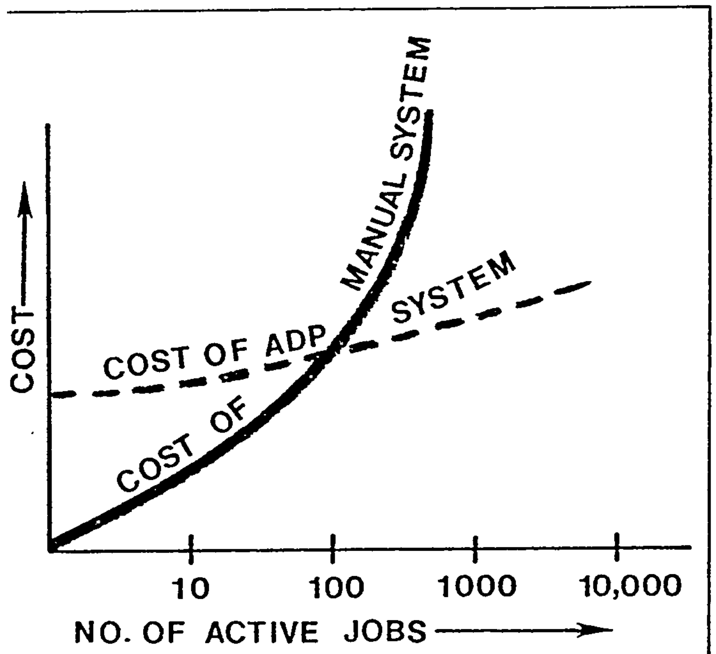

Figure 15. Cost Profiles for Manual and Automated Production Control Systems

Second, automating production control functions by themselves will not guarantee more effective control. The system must be focused on real production needs and must be designed to operate within the shop environment under shop management supervision. Managers must still manage. The system allows managers to identify out of control conditions which require their action.

Third, the dynamics of the waterfront and production shop environment demand an on-line capability for job status tracking and rescheduling. A centralized batch system is too sluggish to provide any real benefits and usually increases the clerical burden on the shop.

Finally, the system must encompass (Figure 16) all production control functions and operate in a closed-loop mode. If it doesn't, then all of the potential benefits will bleed through the holes.

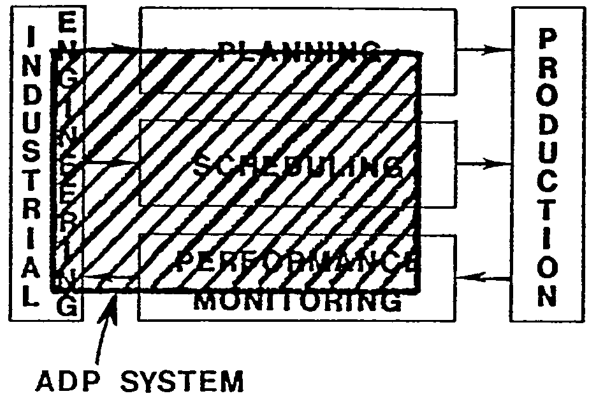

Figure 16. The Proper Place of ADP in Closed-Loop Production Control

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